RADAR STUDIES IN THE SOLAR SYSTEM

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Final Report

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Principal Investigator

Prof. Irwin I. Shapiro

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Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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Radar Studies in the Solar System

This project entails a collaboration involving SAO, NAIC (Arecibo and Cornell), and JPL, including D. B. Campbell, J. F. Chandler, J. K. Harmon, S. J. Ostro, I. I. Shapiro, and M. A. Slade, among others.

Goals

We aid in a study of the solar system by means of ground-based radar. We have concentrated on (i) developing the ephemerides needed to acquire radar data at Arecibo Observatory and (ii) analyzing the resultant data to: test fundamental laws of gravitation; determine the size, shape, topography, and spin vectors of the targets; and study the surface properties of these objects, through their scattering law and polarization characteristics.

Summary of Accomplishments

We are engaged in radar observations of asteroids and comets, both as systematically planned targets and as "targets of opportunity." In the course of the program, we have prepared ephemerides for about 80 asteroids and three comets, and the radar observations have been made or attempted at the Arecibo Observatory, in most cases successfully, and in some cases on more than one apparition. The results of these observations have included echo spectra for the targets and, in some cases, delay-Doppler images and measurements of the total round-trip delay to the targets. Perhaps the most dramatic of these results are the images obtained for asteroids (4179) Toutatis and 1989PB (Castalia), which were revealed to be double-lobed objects by the radar images. Besides these direct results, the radar observations have furnished information on the sizes and shapes of the targets through analysis of the Doppler width of the echoes as a function of time, and on the surface properties (such as composition, bulk density, and roughness) through analysis of the reflectivity and of the polarization state of the echoes. We have also refined the orbits of the observed asteroids as a result of the Doppler (and in some cases delay) measurements from the radar observations. Although the orbits of main-belt asteroids accessible to ground-based radar are quite well known from the available optical data, some near-Earth objects have been seen by radar very soon after their optical discovery (for example, 1990MF, just eight days after discovery). In such cases, the radar results ensure that the object in question can be anticipated and identified at the next apparition.

We have also participated in radar studies of the terrestrial planets. The results of these studies have included both planetary topography profiles from the analysis of round-trip delays to points along the target Doppler equator and determinations of the target spin state. The latter is of special interest in the case of Venus, which is very close to, but not on, a multi-body spin-orbit resonance such that Venus rotates 12 times for every 8 Earth orbits and 13 Venus orbits. As a result, Venus presents nearly the same face toward Earth at each inferior conjunction. Our latest results confirm that the spin state of Venus is slightly off the resonance. The delay measurements from planetary ranging have also been used in combination with other types of range data in testing general relativity with increasing accuracy.

We have also been engaged in radar studies of planetary satellites. Using our ephemerides, Arecibo made radar observations of the Galilean satellites of Jupiter and of Mars' satellite Phobos during the favorable opposition seasons (1988-1992 for Jupiter and 1990 for Mars). An attempt was also made to observe Deimos, but without detecting an echo. In 1997, an attempt was made to observe Saturn's satellite Titan, using the newly upgraded Arecibo radar system for transmitting and the Goldstone radar for receiving, but no echo was detected. The study of satellites by radar is in many ways similar to that of asteroids. The results from these observations have included characterization of the surface properties from the reflectivity and polarization ratio, as well as (in the case of the large satellites of Jupiter) the variation of reflectivity with incidence angle. Also, round-trip delay measurements have been obtained for the satellites Ganymede and Callisto; by combining these, we obtained equivalent ranges to the Jovian system barycenter (inaccessible to direct measurement by radar or by any other means than radio tracking of a spacecraft in the vicinity of Jupiter).

Further, we developed and installed a software package for Arecibo on-site ephemeris correction based on late-arriving optical data or newly-available radar observations of the target. This package gives Arecibo the capability to generate an entirely new radar ephemeris quickly and on-site if valuable new data become available during the course of an observing run (which may happen for newly-discovered Earth-approaching objects).

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